

## Multi-Use Crops and Botanochemical Production

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Scripture tells that early man recognized and used petroleum in the form of asphalts, tars, and oils. Coal gained acceptance in the 16th century, and its use continued to expand into the 20th century. However, before the petroleum industry began to take shape in the mid-19th century and virtually exploded onto the industrial scene with invention of the internal combustion engine, man relied principally on renewable materials for his energy, oil, and hydrocarbon resources. Today, with the decline in readily removable petroleum and rising costs of liquid fuels and chemical feedstocks, man is developing a renewed awareness of the potential value of underutilized and diverse plant species.

Numerous investigators have advanced ideas for development of energy and chemical resources from plants. The energy plantation has been analyzed in detail by Szego and Kemp (1) and Goldstein (2). Concepts of "petrol plantations" have been described by Calvin (3,4), and companies such as Diamond Shamrock (5) and Goodyear (6) are investigating their potential. "Integrated adaptive agricultural systems" have been discussed by Lipinsky (7), and Buchanan and Otey have advanced their "multi-use botanochemical systems" (8). In all of these proposals, entire above-ground material is to be harvested and used. And, in the most advanced schemes, fuel and chemical feedstock production is integrated with production of food and feed.

If fuel is to become a major farm product, new agricultural practices and systems should maximize energy product per unit energy input. Low-energy crop production and energy-efficient processing methods and handling techniques must be components for future agricultural scenarios. Such a scheme has been proposed by Buchanan and Otey (8).

### **BOTANOCHEMICAL SCREENING**

The plant kingdom provides a reservoir of 250,000 to 300,000 known plant species. Fewer than 0.1% have enjoyed any significant commercial recognition in the world. From this wealth of plant resources, we anticipate that new sources of energy-producing plants could be identified and exploited.

Oil- and hydrocarbon-producing plants are especially attractive as future energy and chemical resources. Plants already supply several products competitive with synthetic petrochemicals. These products include tall oil, naval stores, seed oils, and plant oils. For this discussion, we refer to such products collectively as oils and hydrocarbons.

For many years, the U.S. Department of Agriculture has actively pursued a multi-disciplined approach to identify and establish new crops as renewable resources (9). Patterned after the Department's program to identify annually renewable fibrous plants that could be cultivated for papermaking (10), an analytical screening program was instituted in 1974 to identify and evaluate species as sources of multi-use oil- and hydrocarbon-producing crops for food material and energy production (11,12). The multi-use concept requires plant breeders and agronomists to deal with a variety of new crops, each yielding several different products of varying economic value. In screening plant species as potential crops, a rating system was employed that emphasized potential economy of plant production, total biomass yield, and oil and hydrocarbon content (8). Subsequently, all candidates were ranked by this rating system. It should be emphasized that vigorous perennials were given preference over annuals, with the concept that seed-bed preparation would be infrequent for perennials.

Data for over 300 species have been accumulated, and about 40 species have been identified that have sufficient potential to merit further consideration. Nearly all of these species are being further investigated by USDA plant scientists; meanwhile, the screening program continues.

In the original scenario, potential rubber crops were considered. Since then, it was decided to develop guayule (*Parthenium argentatum*) as a domestic source for natural rubber (13). The U.S. rubber market can potentially be supplied by guayule grown in the southwest. Thus, barring discovery of a

exceptional candidate, that decision preempts development of other rubber crops. However, several potential botanochemical crop species produce low-molecular-weight soluble rubbers (14) that would be valuable as a hydrocarbon component of whole-plant oils.

Our analytical procedure consists of stepwise acetone extraction followed by cyclohexane. Subsequently, the acetone-soluble fraction is partitioned between hexane/aqueous ethanol (12,15), and the soluble components are freed of solvents and determined gravimetrically. For lack of specific nomenclature, the botanochemicals isolated by this technique have been referred to as "whole plant oil," "polyphenol," and "polymeric hydrocarbon." Actually, components from these extracts need to be further characterized. However, petroleum refinery processes may be sufficiently insensitive to allow use of carbon-hydrogen rich compounds represented by a broad spectrum of structures. For example, consider the diverse chemicals ranging from methanol to natural rubber which have been converted to gasoline (16). Thus, chemical species may be important if chemical intermediates are being generated but may be nonconsequential for production of fuels, solvents, carbon black, and other basic chemicals.

### PROMISING SPECIES FOR WHOLE PLANT USE

Plant families from which more than one promising species has been identified thus far are Anacardiaceae, Asclepiadaceae, Coprifoliaceae, Compositae, Euphorbiaceae, and Labiatae. However, representative species from ten other families have been identified as having sufficient potential to merit further consideration. Undoubtedly, the sample base is too incomplete to establish any trends.

Crop ratings and proximate composition of promising species are summarized in Table I. Species containing the greater amount of oil, all exceeding 6%, were *Ambrosia trifida*, *Campanula americana*, *Asclepias hirtella*, and the three Euphorbiaceae. Those with the most abundant polymeric hydrocarbon, exceeding 2%, were *Asclepias subulata*, *A. tuberosa*, *Crystostegia grandiflora*, *Cacalia atriplicifolia*, *Parthenium argentatum*, *Elaeagnus multiflora*, and *Agropyron repens*. Seven species had more than 15% of the polar fraction labelled polyphenol, i.e., *Acer saccharinum*, *Rhus glabra*, *Lonicera tatarica*, *Elaeagnus multiflora*, *Xylococcus bicolor*, *Teucrium canadensis*, and *Prunus americanus*. And one species, *Vernonia altissima*, had more than 0% of apparent protein.

Protein contents are calculated from Kjeldahl nitrogen values by multiplying by 6.25 as the nitrogen equivalent for protein. However, nonproteinous nitrogenous components must be subtracted.

sion of leafy plants as protein resources, Kohler *et al.* remind us that in addition to desirable nutrients, most plants contain compounds which, if not appropriately dealt with, may be deleterious to animals (17). They also discuss several processing schemes which may provide insights into processing plants identified during the screening program.

### PLANT OIL AND HYDROCARBON-PRODUCING SPECIES

During World War II, *Parthenium argentatum*, *Cryptostegia grandiflora*, *Crysothamnus nauseosus*, and *Solidago leavenworthii* were given considerable attention as possible domestic rubber sources (18). *P. argentatum* is undergoing vigorous reinvestigation (19). *Taraxacum kok-sagbyz* (Russian dandelion), although not listed in Table I principally because of botanical characteristics, was also a strong candidate as a potential rubber crop during the 1940's (20). See Table II for comparisons of *Hevea brasiliensis* rubber molecular weights with those of species identified by Swanson, Buchanan, and Otey (14).

Relatively few plant species have been proposed as potential U.S. oil and hydrocarbon crops. As previously stated, there is considerable current interest in guayule for production of natural rubber. Rubber is a pure hydrocarbon easily depolymerized into isoprene or reformed into gasoline (16). For this use, low molecular weight may be an advantage; the polyisoprene probably is best extracted as a hydrocarbon component of a whole-plant oil. A milkweed, *Asclepias speciosa*, is being grown experimentally in Utah. USDA agronomists are studying the common milkweed, *Asclepias syriaca*, and a few rubber- and oil-producing species in other plant families.

Gutta has been found in several Gramineae species (21). Although these species are low in combined oil and hydrocarbon content, *Elymus canadensis* is being grown in small plots to test its response to plant growth stimulants, and the genetic variability of *Agropyron repens* is being evaluated.

A few Euphorbiaceae have been suggested as crops for production of a whole-plant oil low in polyisoprene content. Calvin has drawn particular attention to *Euphorbia lathyris* and *Euphorbia tirucalli*, species that are accustomed to arid lands, and has suggested that Asclepiadaceae and Euphorbiaceae deserve increased attention because they generally contain oil- and hydrocarbon-rich latexes. Hexane-extractable material from *E. lathyris* representing 4-5% of plant dry weight, has been reported to have a viscosity of 100-200 lb (22). This material consists almost entirely of

Table 1. COMPOSITION AND CROP RATING OF REPRESENTATIVE BOTANO-CHEMICAL-PRODUCING SPECIES\*

Family-Genus-Species	Common Name	Crude Protein, %	Polyphenol Fraction, %	Oil Fraction, %	Polymeric Hydrocarbons %	Crop Type <sup>b</sup>	Rating
Aceraceae							
<i>Acer saccharinum</i>	Silver maple	16.3	19.8	2.4	0.39	—	9
Anacardiaceae							
<i>Rhus glabra</i>	Smooth sumac	7.1	20.2	5.9	0.21	W	10
<i>Rhus laurina</i>	Laurel sumac	8.1	10.5	5.5	1.44	W	8
Apocynaceae							
<i>Apocynum androsaemifolium</i>	Spreading dogbane	17.0	7.8	3.0	0.50	R,W	10
Asclepiadaceae							
<i>Asclepias hirtella</i>	Green milkweed	14.2	4.4	7.7	0.49	R	10
<i>Asclepias incarnata</i>	Swamp milkweed	11.0	11.5	3.0	1.87	R	10
<i>Asclepias subulata</i>	Desert milkweed	—	—	11.4 <sup>c,d</sup>	2.95 <sup>c</sup>	R	8
<i>Asclepias syriaca</i>	Common milkweed	12.3	8.0	4.8	1.54	R	9
<i>Asclepias tuberosa</i>	Butterfly-weed	8.1	12.3	3.1	2.84	R	9
<i>Cryptostegia grandiflora</i>	Madagascar rubber vine	—	—	6.7 <sup>c,d</sup>	2.19 <sup>c</sup>	R	10
Caprifoliaceae							
<i>Lonicera tatarica</i>	Red tatarian honeysuckle	10.2	15.8	3.4	1.77	R	9
<i>Sambucus canadensis</i>	Common elder	6.5	6.6	2.2	0.52	R	10
Symphoricarpos							
<i>orbiculatus</i>	Coral berry	5.9	11.1	2.3	0.81	R	10
<i>rosteum perfoliatum</i>	Tinker's weed	7.1	14.2	2.6	1.43	R	10
Campanulaceae							
<i>Campanula americana</i>	Tall bellflower	9.7	6.2	6.5	0.99	R,W	10

Compositae							
<i>Ambrosia trifida</i>	Giant ragweed	11.4	4.4	8.3	0.60	R	10
<i>Cacalia atriplicifolia</i>	Pale Indian-plantain	11.7	9.4	3.4	3.46	R	8
<i>Chrysanthemum nauseosus</i>	Rabbitbrush	—	—	11.5 <sup>c,d</sup>	1.67 <sup>c</sup>	R	8
<i>Cirsium discolor</i>	Field thistle	5.9	3.9	5.8	0.40	R,W	10
<i>Eupatorium altissimum</i>	Tall boneset	8.6	10.8	5.9	0.56	R,W	10
<i>Helianthus</i>							
<i>grosseserratus</i>	Cut-leaf sunflower	8.8	9.2	2.3	0.76	R	10
<i>Parthenium argentatum</i>	Guayule	18.1	7.7	4.4	4.98	R	10
<i>Rudbeckia subtomentosa</i>	Sweet coneflower	5.9 <sup>a</sup>	7.6 <sup>b</sup>	2.4 <sup>b</sup>	1.22 <sup>e</sup>	R	10
<i>Silphium integrifolium</i>	Rosin weed	6.2	7.0	2.8	0.79	R	10
<i>Silphium laciniatum</i>	Compass plant	9.8	8.1	3.3	0.75	R	10
<i>Silphium</i>							
<i>terbinthinaceum</i>	Prairie dock	4.5	6.3	2.8	0.94	R	10
<i>Solidago graminifolia</i>	Grass-leaved goldenrod	5.6	13.4	2.6	1.51	R	10
<i>Solidago leavenworthii</i>	Edison's goldenrod	12.9	8.9	5.0	1.52	R	8
<i>Solidago ohioensis</i>	Ohio goldenrod	5.8	8.6	2.5	0.54	R	10
<i>Solidago rigida</i>	Stiff goldenrod	4.9	6.8	2.4	1.48	R	10
<i>Sonchus arvensis</i>	Sow thistle	9.3 <sup>a</sup>	11.0 <sup>b</sup>	5.3 <sup>b</sup>	0.72 <sup>u</sup>	R,W	10
<i>Veronica altissima</i>	Tall ironweed	21.6	6.9	3.1	0.38	—	10
<i>Veronica fasciculata</i>	Ironweed	11.4	8.4	5.4	0.39	R	10
Elaeagnaceae							
<i>Elaeagnus multiflora</i>	Cherry elaeagnus	11.9	18.9	2.3	2.03	R	10
Ericaceae							
<i>Xylococcus bicolor</i>	—	7.2	18.6	5.4	1.08	R	10
<i>Elymus canadensis</i>	Canada wildrye	7.0	5.5	1.7	1.35	G	11

**Table I. COMPOSITION AND CROP RATING OF REPRESENTATIVE BOTANO-CHEMICAL-PRODUCING SPECIES<sup>a</sup>**  
(Continued)

Family-Genus-Species	Common Name	Crude Protein, %	Polyphenol Fraction, %	Oil Fraction, %	Polymeric Hydrocarbons %	Crop Type <sup>b</sup>	Rating
Euphorbiaceae							
<i>Euphorbia dentata</i>	Cut-leaf spurge	19.4	4.1	11.2	0.20	—	—
<i>Euphorbia lathyris</i>	Mole plant	12.7	7.6	9.9	0.40	—	9
<i>Euphorbia pulcherrima</i>	Poinsettia	16.4	6.4	6.3	0.66	W	10
Gramineae							
<i>Agropyron repens</i>	Quackgrass	12.2	4.6	2.4	1.95	G	10
Labiatae							
<i>Pycnanthemum incanum</i>	Mountain mint	13.3	8.0	2.2	1.36	R	10
<i>Teucrium canadensis</i>	American germander	14.3	16.7	2.7	1.44	R	10
Lauraceae							
<i>Sassafras albidum</i>	Sassafras	8.9	14.4	5.7	0.23	W	10
Phytolaccaceae							
<i>Phytolacca americana</i>	Pokeweed	15.5 <sup>c</sup>	5.9 <sup>d</sup>	3.4 <sup>e</sup>	0.17 <sup>e</sup>	—	10
Rhamnaceae							
<i>Ceanothus americanus</i>	New Jersey tea	12.4	12.8	3.4	0.67	W	10
Rosaceae							
<i>Prunus americanus</i>	Wild plum	17.3	18.5	4.6	0.20	—	10

<sup>a</sup> Values are moisture and ash free, crude protein is calculated from Kjeldahl nitrogen with the factor 6.25

<sup>b</sup> Identified by infrared G = gutta, R = rubber, W = wax.

<sup>c</sup> Literature values.

<sup>d</sup> Also contains Polyphenol fraction.

<sup>e</sup> Values are moisture free but are not corrected for ash.

Table II. MOLECULAR WEIGHT OF NATURAL RUBBERS  
RELATIVE TO *HEVEA BRASILIENSIS* RUBBER

Species	Common Name	Ratio
<i>Hevea brasiliensis</i> Mull. arg.	Rubber tree	1.00
<i>Parthenium argentatum</i> A. Gray	Guayule	0.98
<i>Pycnanthemum incanum</i> (L.) Michx.	Mountain mint	0.38
<i>Lamiaeum galeobdolon</i> (L.) Ehrend. and Polatsch	Yellow archangel	0.32
<i>Monarda fistulosa</i> L.	Wild bergamot	0.32
<i>Veronia fasciculata</i> Michx.	Ironweed	0.32
<i>Symphoricarpos orbiculatus</i> Moench	Coral berry	0.28
<i>Sonchus arvensis</i> L.	Sow thistle	0.25
<i>Xylcoccus bicolor</i> Nutt.	Two-color woodberry	0.25
<i>Melissa officinalis</i> L.	Balm	0.24
<i>Silphium integrifolium</i> Michx.	Rosinweed	0.22
<i>Helianthus hirsutus</i> Raf.	Hirsute sunflower	0.21
<i>Cirsium vulgare</i> (Savv.) Ten.	Bull thistle	0.20
<i>Cacalia atriplicifolia</i> L.	Pale indian plantain	0.20
<i>Euphorbia glyptosperma</i> Engelm.	Ridgeseed Euphorbia	0.20
<i>Monarda didyma</i> L.	Oswega tea	0.20
<i>Lonicera tatarica</i>	Tartarian honeysuckle	0.19
<i>Triosteum perfoliatum</i> L.	Tinker's weed	0.18
<i>Solidago altissima</i> L.	Tall goldenrod	0.18
<i>Cirsium discolor</i> (Muhl.) Spreng.	Field thistle	0.18
<i>Solidago graminifolia</i> (L.) Salisb.	Grass-leaved goldenrod	0.18
<i>Apocynum cannabinum</i> L.	Indian hemp	0.16
<i>Polymnia canadensis</i> L.	Leafy cup	0.16
<i>Gnaphalium obtusifolium</i> L.	Fragrant cudweed	0.16
<i>Silphium terebinthinaceum</i> Jacq.	Prairie dock	0.15
<i>Euphorbia pulcherrima</i>	Poinsettia	0.15
<i>Asclepias incarnata</i> L.	Swamp milkweed	0.14
<i>Grindelia squarrosa</i> (Pursh.) Duval.	Tarweed	0.13
<i>Veronia altissima</i> Nutt.	Ironweed	0.13
<i>Solidago rigida</i> L.	Stiff goldenrod	0.12
<i>Euphorbia corollata</i> L.	Flowering spurge	0.12
<i>Helianthus grosseserratus</i> Martens	Sawtooth sunflower	0.12
<i>Elaeagnus multiflora</i> Thunb.	Cherry Elaegnus	0.12
<i>Rudbeckia laciniata</i> L.	Sweet coneflower	0.12
<i>Pycnanthemum virginianum</i> (L.) Durand & Jackson	Mountain mint	0.11
<i>Campsis radicans</i> (L.) Seem. ex Bur.	Trumpet creeper	0.11
<i>Chenopodium album</i> L.	Lambsquarter	0.11
<i>Monarda punctata</i> L.	Horsemint	0.11
<i>Apocynum androsaemifolium</i> L.	Spreading dogbane	0.11
<i>Asclepias tuberosa</i> L.	Butterfly weed	0.10
<i>Nepeta cataria</i> L.	Catnip	0.10
<i>Teucrium canadense</i> L.	American germander	0.10
<i>Solidago ohioensis</i> Riddell	Ohio goldenrod	0.10
<i>Artemisia vulgaris</i> L.	Common mugwort	0.10
<i>Aster laevis</i> L.	Smooth aster	0.10
<i>Asclepias syriaca</i> L.	Common milkweed	0.09
<i>Artemisia abrotanum</i> L.	Southernwood	0.09
<i>Campanula americana</i> L.	Tall bellflower	0.09
<i>Centaurea vochinensis</i> Bernh.	Knapweed	0.08



**Table II. MOLECULAR WEIGHT OF NATURAL RUBBERS  
RELATIVE TO *HEVEA BRASILIENSIS* RUBBER**

(Continued)

<i>Physostegia virginiana</i> (L.) Benth.	Obedient plant	0.08
<i>Verbena urticifolia</i> L.	White vervain	0.08
<i>Euphorbia cyparissias</i> L.	Cypress spurge	0.08
<i>Ocimum basilicum</i> L.	Purple basil	0.08
<i>Asclepias hirtella</i> (Pennell Woodson)	Milkweed	0.08
<i>Achillea millefolium</i> L.	Yarrow	0.07
<i>Phyla lanceolata</i> (Michx.) Greene	Frog fruit	0.07
<i>Gaura biennis</i> L.	Gaura	0.07

of polycyclic triterpenoids. *E. lathyris* is being further evaluated at the University of Arizona (5), and USDA is evaluating *E. pulcherrima* and several other Euphorbiaceae.

During the summer of 1979, USDA made a special effort to collect Leguminosae species. And in September 1979, Calvin drew attention to the Leguminosae *Copaifera langsdorfii* which, he observed, produces virtually pure diesel fuel (23).

### POLYPHENOLS AND TANNINS

The rather simple solvent classification schemes yield complex fractions of botanochemicals. Their detailed composition depends not only on the species but also on maturity of the plant and the method of extraction (15,22). The polar fraction isolated by acetone extraction and readily soluble in 87.5% aqueous ethanol, termed "polyphenol" by Buchanan and coworkers (11,12), no doubt consists of phenolics and a wide variety of other substances. For plants of high tannin content, (e.g., *Rhus glabra*) the polyphenol fraction might well be called tannin. (24)

### HARVESTING AND PROCESSING SCHEMES

Harvesting and processing technologies will need to be developed and individually tailored to each species. A multi-disciplined approach is essential to capture the full potential offered by the various species. While it is beyond the scope of this review to elaborate on the many facets, major areas of concern are: harvesting method and timing, handling, storage, and separation and recovery of materials. For example, see some USDA experiences with the development of promising new crops crambe and kenaf (25,26).

Processing of whole plant materials for oil and hydrocarbon has been discussed by Buchanan and Otey (8) and Nivert and coworkers (27). In the process envisioned, baled plant material is flaked in equipment common to the soybean processing industry. The flakes are subsequently extracted by the appropriate solvent, perhaps by a sequential extraction using several solvents.

### LIGNOCELLULOSIC RESIDUE

In all plant materials, the major component will be the cellular lignocellulosic material. Several possible uses for this material exist. Some of the more attractive are cattle feed; fiber for pulp, paper, and board; chemical feedstock; or energy (8,11,12). Detailed evaluation of the cellular portion should provide bases for suggesting their most appropriate uses.

## CONCLUSIONS

Green plants are solar-powered chemical factories that convert carbon dioxide and water into a variety of energy-rich compounds. Crops can be developed to help provide renewable sources of fuels and chemicals and at the same time to provide a continuing source of feed and food. Several candidates have been identified, which can become future crops for American Agriculture.

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